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TECHNICAL PICTORIAL HISTORY OF GROUND BASED OPTICAL MEASUREMENTS OF DNA/USAF - PL EXCEDE III ELECTRON BEAM EXCITATION OF THE UPPER ATMOSPHERE

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On 26 April 1990 the USAF Phillips Laboratory, Geophysical Directorate conducted an upper atmospheric electron beam excitation experiment to study the in-situ atmospheric constituent excitation efficiency, relative excited state populations, and excited state decay rates as a function of altitude at the White Sands Missile Range, New Mexico. TIC deployed and operated ground based optical instrumentation from two orthogonal perspectives in support of the DNA/PL EXCEDE III experiment. This report provides a technical pictorial history of the optical emissions of the electron beam excited atmosphere from both film and video records obtained by TIC and by MIT/Lincoln Laboratory from that experiment.

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CONTENTS

INTRODUCTION

The DNA/PL EXCEDE III experiment was the most recent in an evolving series of rocket-borne upper atmospheric research programs to study the collisional excitation, relaxation, and optical quenching processes of the ambient atmospheric molecules and atoms in both the visible and infrared regions of the optical spectrum. The collisional excitation is accomplished by utilizing an electron accelerator gun to produce a beam of energetic electrons which --when field aligned-- produce a narrow (Larmor diameter) sweeping excitation region in the atmosphere along the ballistic flight path. By cycling the electron beam payload on and off during its flight the optical emissions of the atmosphere during continuing excitation and during molecular and atomic relaxation can be observed independently as a function of flight altitude. In the EXCEDE III experiment, sophisticated optical recording spectral instrumentation was flown in a separate sensor module payload alongside (sic) the electron gun payload for continuous atmospheric emission observation in the changing dosed region. In addition to the sensor payload instrumentation, a ground optics program was performed by Technology International Corporation to record the changing beam geometry and extent of the beam as well as other long lived visible aspects of the experiment. Overall the visible emissions were characterized by a short lived molecular nitrogen emission during beam on and a long lived atomic oxygen decay emission during beam off from the wide spectrum of incident electron energies from the accelerator beam as well as secondary electrons from prior collisions of energetic electrons.

The EXCEDE III experiment was conducted at the White Sands Missile Range on 26 April 1990. Launch occurred at 07:01:00UT nominal. The experiment utilized an Aries booster rocket launched from SULF Site at an azimuth of approximately 191 degrees so as to stay nominally

within the same geomagnetic meridian plane throughout the flight. The geomagnetic dip angle in this geographic region is 61 degrees.

The electron accelerator gun payload was operated at 2.6kV with a gun current of 16.5 to 18 amps. The gun was operated in a cycled pulse mode of 4.7 seconds beam on with an interpulse period of 2.35 seconds beam off for 26 continuous cycles. * Primary atmospheric dosing occurred throughout the altitude range of 90 to 115 km for the EXCEDE III experiment. Pulses 21 through 26 occurred from 90 km to about 60 km on the downleg. Apogee for the experiment occurred at 115 km at t + 194 seconds during pulse number 11.

Table 1 presents the time and duration of the 26 electron beam pulses together with the approximate midpoint altitude of the payload during a specific pulse. The pulse times are referenced to t=0 launch time in column 2 and to UT in column 3, the latter corresponding to the date-time imprint on the bottom of the video frame data.

* Pulses 1 and 2 did not achieve full electron beam gun power.

TABLE 1

EXCEDE III PULSE TIMING - ALTITUDE PARAMETERS

PULSE	ON-OFF TIME (Ref. to UT)	ON-OFF (UT)	ALTITUDE (KM)
1	t+119.4 - 124.2	7:02:59.4 - 7:03:04.2	90.5
2	t+126.5 - 131.3	7:03:06.5 - 7:03:11.3	95.5
3	t+133.6 - 138.4	7:03:13.6 - 7:03:18.4	99.5
4	t+140.7 - 145.5	7:03:20.7 - 7:03:25.5	103.0
5	t+147.8 - 152.6	7:03:27.8 - 7:03:32.6	106.0
6	t+154.9 - 159.7	7:03:34.9 - 7:03:39.7	109.0
7	t+162.0 - 166.8	7:03:42.0 - 7:03:46.8	111.0
8	t+169.1 - 173.9	7:03:49.1 - 7:03:53.9	112.5
9	t+176.2 - 181.0	7:03:56.2 - 7:04:01.0	114.0
10	t+183.3 - 188.1	7:04:03.3 - 7:04:08.1	115.0
11	t+190.4 - 195.2	7:04:10.4 - 7:04:15.2	115.0
12	t+197.5 - 202.3	7:04:17.5 - 7:04:22.3	115.0
13	t+204.6 - 209.4	7:04:24.6 - 7:04:29.4	114.0
14	t+211.7 - 216.5	7:04:31.7 - 7:04:36.5	113.0
15	t+218.8 - 223.6	7:04:38.8 - 7:04:43.6	111.5
16	t+225.9 - 230.7	7:04:45.9 - 7:04:50.7	109.5
17	t+233.0 - 237.8	7:04:53.0 - 7:04:57.8	107.0
18	t+240.1 - 244.9	7:05:00.0 - 7:05:04.9	104.0
19	t+247.2 - 252.0	7:05:07.2 - 7:05:12.0	100.0
20	t+254.3 - 259.1	7:05:14.3 - 7:05:19.1	96.0

TABLE 1 (Continued)

PULSE	ON-OFF TIME (Ref. to UT)	ON-OFF (UT)	ALTITUDE (KM)
21	t+261.4 - 266.1	7:05:21.4 - 7:05:26.1	92.0
22	t+268.5 - 273.3	7:05:28.5 - 7:05:33.3	87.0
23	t+275.6 - 280.4	7:05:35.6 - 7:05:40.4	81.0
24	t+282.7 - 287.5	7:05:42.7 - 7:05:47.5	76.0
25	t+289.8 - 294.6	7:05:49.8 - 7:05:54.6	69.0
26	t+296.9 - 301.7	7:05:56.9 - 7:06:01.7	63.0

DISCUSSION

The photographic data frames incorporated into this EXCEDE III Technical Pictorial History are presented as representative of the ground optics coverage of this experiment and selected so as to generally illustrate the history of the observed phenomena along the flight path. The ground based optical measurements were performed from two nominally orthogonal site locations for this nocturnal experiment based upon prior similar experiment. These sites included RIM FIRE Site, viewing generally along the geomagnetic merdian plane of the experimental flight trajectory and, COWAN Site, viewing the experiment from the side or more or less normal to the geomagnetic merdian plane. The location of these sites relative to the location of SULF Site from which the rocket payload was launched in a south westerly direction (191^{o} True) is shown in Appendix A.

The TIC optical instrumentation was operated from both tracking and pre-pointed fixed mounts during the experiment. Instrumentation consisted of Photographic Film cameras, Intensified Film cameras, Intensified Video cameras, and several Spectral Grating cameras. The instrumentation was operated so as to record the geometry of the beam on condition and, in addition, the residual emissions during beam off conditions. The former primarily from payload tracking cameras and the latter from pre-pointed fixed camera systems.

Figure 1 shows the pulsed electron beam images as the electron accelerator gun cycles on and off through approximately pulse number 20 as seen from RIM FIRE Site in the north. Pulses 1 and 2 of this ballistic photograph did not achieve full continuous power and the first discernable pulse in this figure is probably pulse number 3, at approximately 99 km altitude on the upleg. The reddish continuous

line image between pulses is the glowing booster rocket motor which flew ballistically alongside the experimental payloads throughout the flight. * The greenish trapezoidal images of the beam swept atmosphere can be seen to change somewhat in brightness and exhibit an apparently wider image as the payload transits the less dense atmospheric region near apogee (115 km altitude).

Figure 2 obtained from a spectral grating camera at the side viewing COWAN Site to the east of the experiment, shows a complementary ballistic image** of the EXCEDE III flight trajectory. In this side view the separation of the pulses and their trapezoidal shaped swaths in the atmosphere are more clearly evident than in figure 1. Pulse number 11 (apogee) is visible directly below the bright zero order star trail at the top center of the photograph. The fact that the flight trajectory appears to continue to rise beyond pulse 11 is due to the relative perspective of the viewing instrumentation with respect to the trajectory path.

Figures 3 through 7 show selected data frames of the electron beam induced emissions from pulse 4 through pulse 17 obtained from an intensified video camera operated from a primary range tracking mount located at the side viewing COWAN Site. Figure 3 shows the upward pointing field aligned forward beam during pulse 4 (beam on), the (over exposed) local emissions near the accelerator gun payload body, the backscatter beam, and the extended rocket booster debris

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* Burn out of the booster motor at t+63 seconds is visible at approximately 60 percent of the visible portion of the flight upleg.

** The primary (brightest) spectral image is probably from excited oxygen emissions; the background star field is spectrally dispersed together with zero-order images.

trail trailing off along the trajectory path from an altitude of about 103 km.

Figures 4 and 5 show the field aligned beam during pulse 6 (beam on) and pulse 11 (beam on), respectively. The dramatic increase in visible beam length in the 100-115 km altitude regime is apparent in these figures in contrast to figure 3. Figure 5, pulse 11, shows the beam at experiment apogee.

Figure 6 shows the continuing visible image during the period pulse 13 (beam off) This image is typical of the residual atmospheric emissions exhibiting a few second decay time seen between beam on conditions. The star-like image to the left of the lower region of the emissions is the rocket booster from which the continuing debris trail is still visible.

Figure 7 shows the again shortened electron beam image for pulse 17 (beam on) near 107 km altitude on the downleg trajectory. The fact that the trajectory direction (as evidenced by the weak booster trail) is nearly normal to the field aligned beam accounts for the widened swath of excited atmosphere behind the beam. (This effect is also clear in the ballistic photograph shown in figure 2). Figure 8 is a second video frame photograph of the pulse 11 (beam on) image from a wider field video camera system showing the fuller extent of the beam length than shown in the figure 5, pulse 11 photograph.

Figures 9 through 11 show a series of time integrated side view photographs of the beam induced long lived atmospheric emissions during pulses 15, 17, and 19 respectively, from approximately 111 km to 100 km on the payload downleg. In figure 9, a two second exposure, one can readily see the elongated bright region corresponding to the payload

track with the field aligned forward beam extending to the upper left and the weak backscatter beam to the lower right. Also visible continuously throughout this data record is the sharper image of the heated booster vehicle below and slightly to the left of the accelerator payload.

Figure 10 shows a four second exposure which includes the last portion of pulse 17 beam on and the interval of beam off prior to pulse 18. The dramatic decrease in recordable forward beam length and increase in relative brightness due to the increased atmospheric density is clear in examining these two figures.

Figure 11 shows a four second exposure of pulse 19 as it transits the 100 km altitude regime on downleg. In this case the much brighter and significantly shorter image of the forward beam is quite evident again. If it can be assumed that the slant range to the payload object is 130 km, the respective recorded beam lengths for figures 9, 10, and 11 are 11 km, 6.5 km, and 2.6 km for the forward beam.

Figure 12 was reproduced from an intensified film record, taken at a one second exposure. This exposure was made during pulse 14 beam off with the payload at approximately 113 km altitude. This camera was one of several deployed to record booster debris trail history and, as with the intensified video camera records (figures 3 through 7) shows an extensive although weak self luminous trail. The booster body image can be seen quite distinctly as in figure 6 with the beam off.

Figures 13 through 17 inclusive are photographic prints of an intensified video record made by MIT Lincoln Laboratory at the WSMR RIM FIRE Site to the north of the EXCEDE III launch site. This narrow field long focal length video telescope was operated in a tracking mode throughout the 26 pulse experiment and shows unique aspects of the

close in beam geometry. Figure 13 shows the beam on image for pulse number 5 at 106 km altitude on the experiment upleg. From the north site perspective at this time in the flight the forward beam, field aligned up the field (61° dip angle), appears pointing down in the photograph. Also evident in the MIT record is the wind sheared image of the booster motor trail close in to the payload location. *

Figure 14 shows the forward beam (pointed down) and the backscatter beam from pulse number 10 near apogee at approximately 115 km altitude. Superimposed on top of the backscatter beam is an extended image swath produced by the long lived excited atmosphere behind the accelerator payload.

Figure 15 shows the image of the heated booster vehicle and the trailing long lived atmospheric emissions during pulse number 10 beam off. The residual field aligned image protruding down from the payload is generally believed to be video target surface persistancy in this fine tracked optical system.

Figure 16 shows the electron beam on during pulse number 15 at approximately 111 km altitude. In this photograph the forward beam is now seen projecting left from the payload as the relative trajectory perspective has changed overall. The backscatter beam is seen to the right of the payload region. The bright extended image swath behind the payload (i.e. upward) is due to the beam excited atmosphere while the visible trail behind the circular booster image is a consequence of continuing debris from the booster vehicle. Figure 17 is a photograph

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* In this and succeeding photographs in this series the circular image appearing to the left of the payload is a consequence of internal optical reflections only.

of pulse 15 beam off. In this figure the heavily dosed atmosphere image is seen at the top of the picture. The sharp lower boundary (centered on the right hand payload trail) corresponds to the shut off of the pulse 15 beam. As in figure 15 the residual field aligned sharp image is probably due to video target persistancy. The EXCEDE Aries booster image and its visible debris trail is clearly evident in this figure as well.

Figure 18 is a time integrated spectral ballistic camera record of the EXCEDE III flight trajectory beginning at about t+90 seconds as seen from RIM FIRE Site to the north of the launch area. (The exposure starts at the upper right towards the end of the upleg trajectory and continues through apogee and into the downleg phase). The zero order image is the brightest image in the center of the photograph. The first order spectrally dispersed images are the group to the right of the zero order including the bright oxygen line and, to the left somewhat, the weaker nitrogen emissions. The second order spectra are seen further to the right dispersed a factor of two relative to the first order spectrum.

Table 2 lists, adjacent to the photographic print section, the pertinent parameters associated with each individual picture. This table can be cross correlated with table 1 for additional information when reviewing a particular photograph.

FIGURE CAPTION LIST

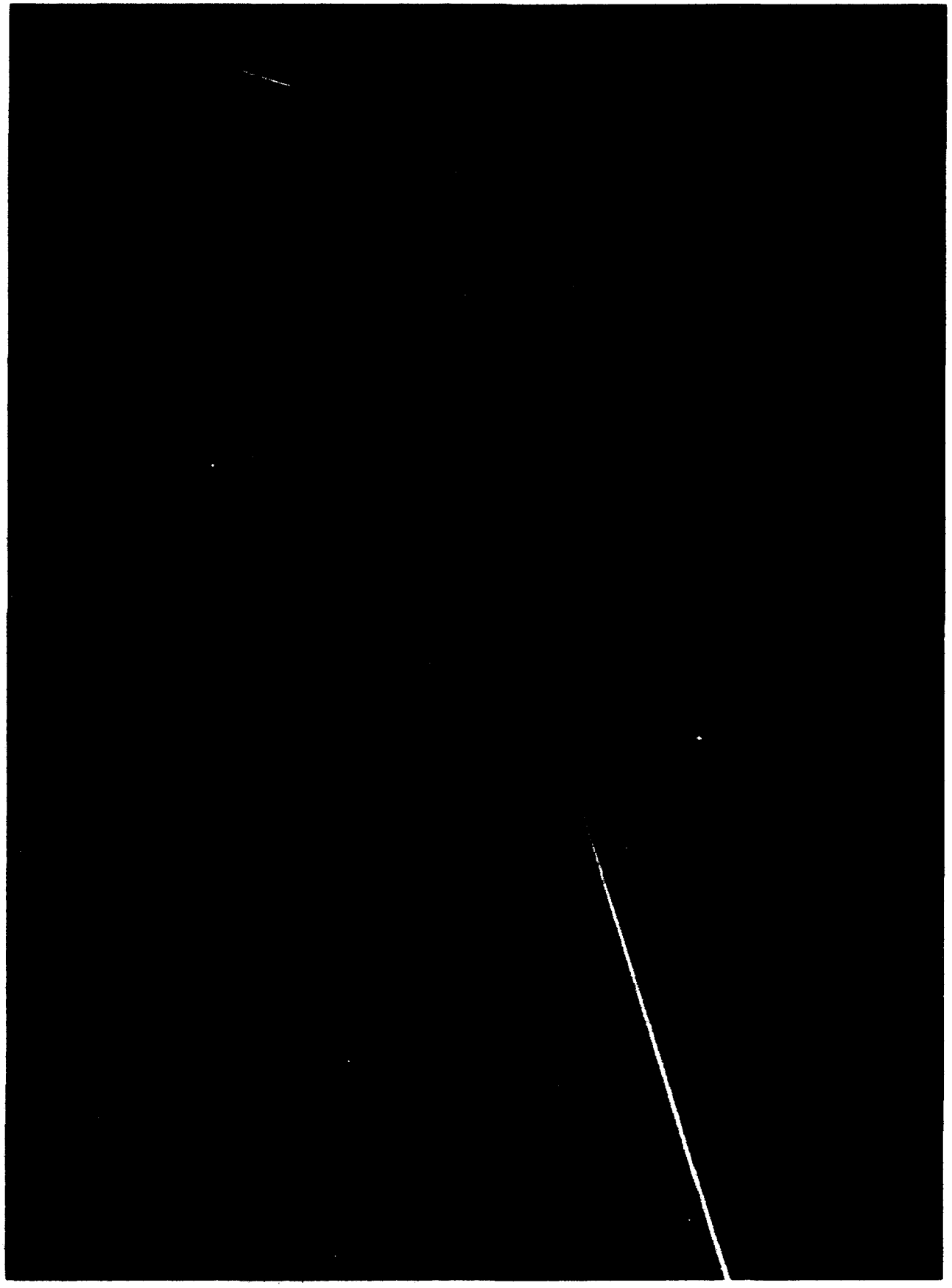
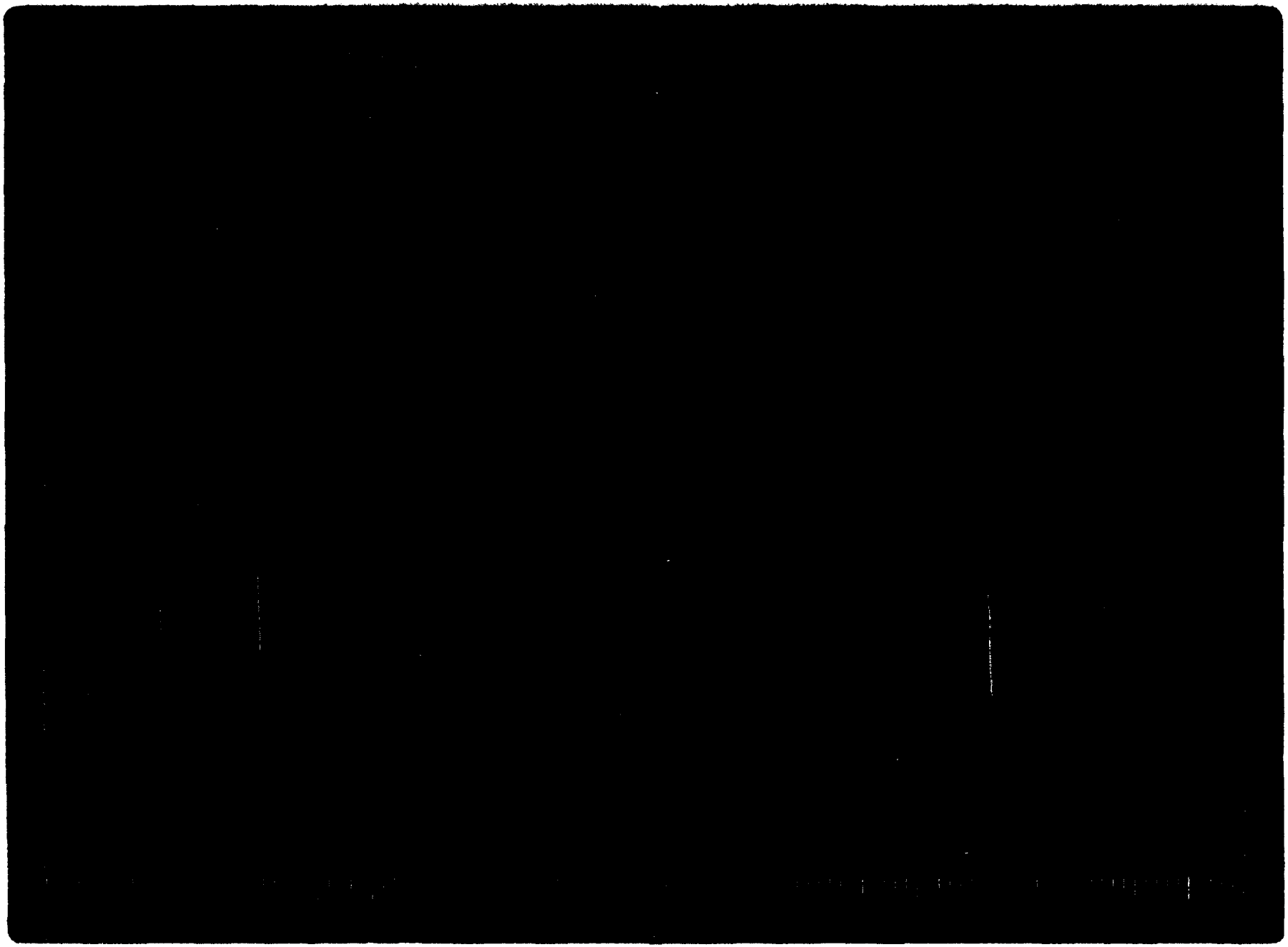


FIGURE 1



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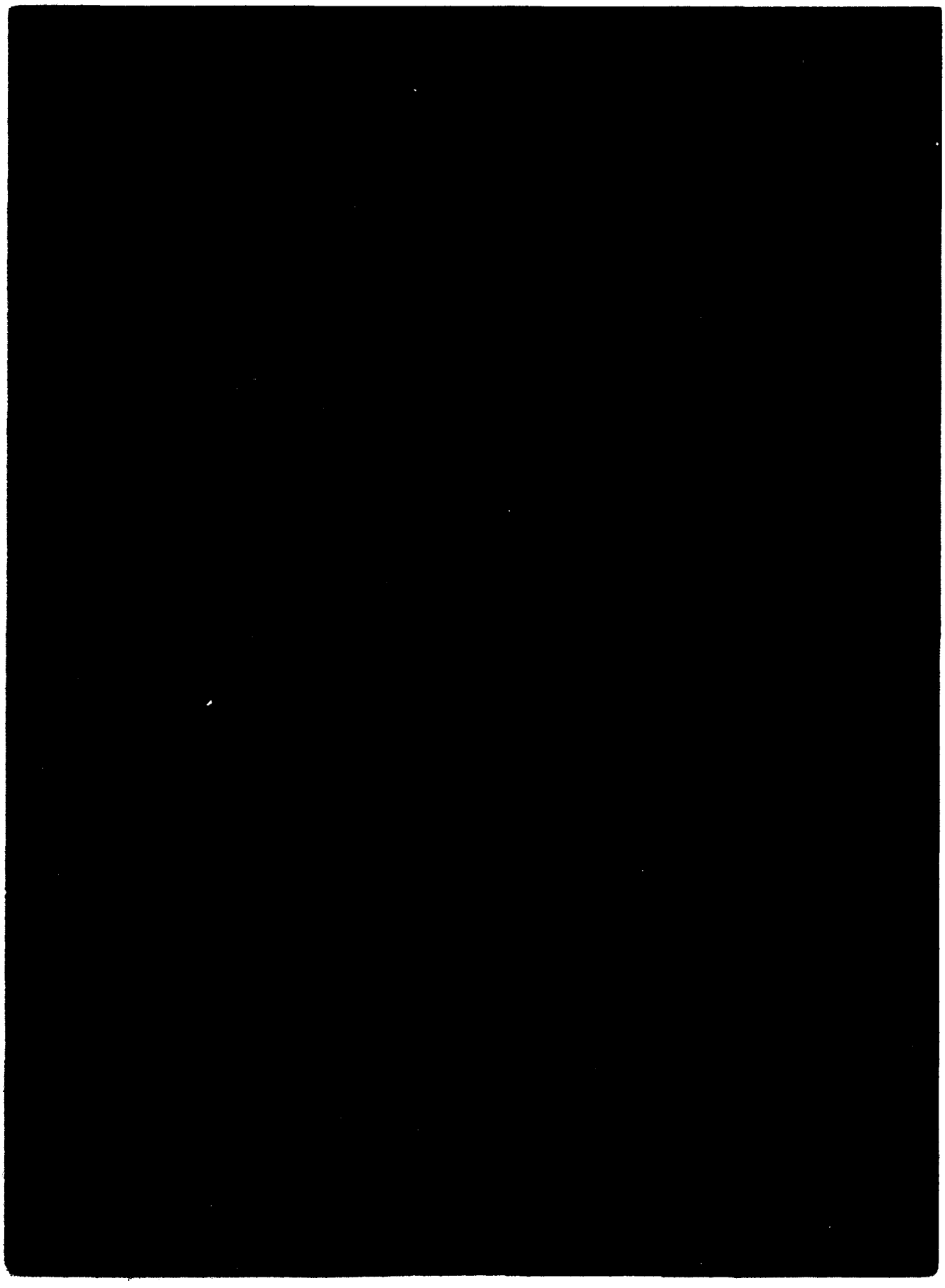

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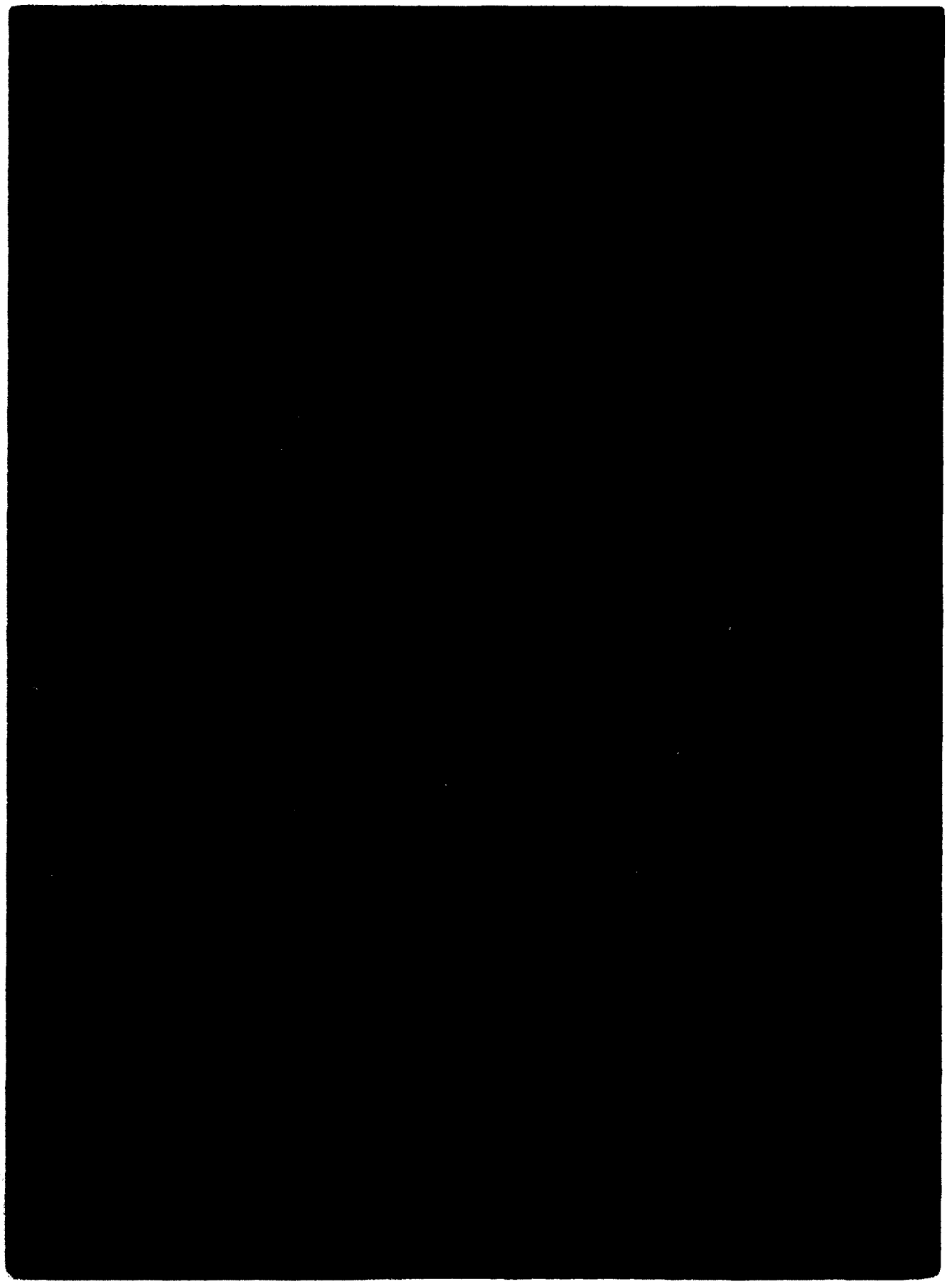

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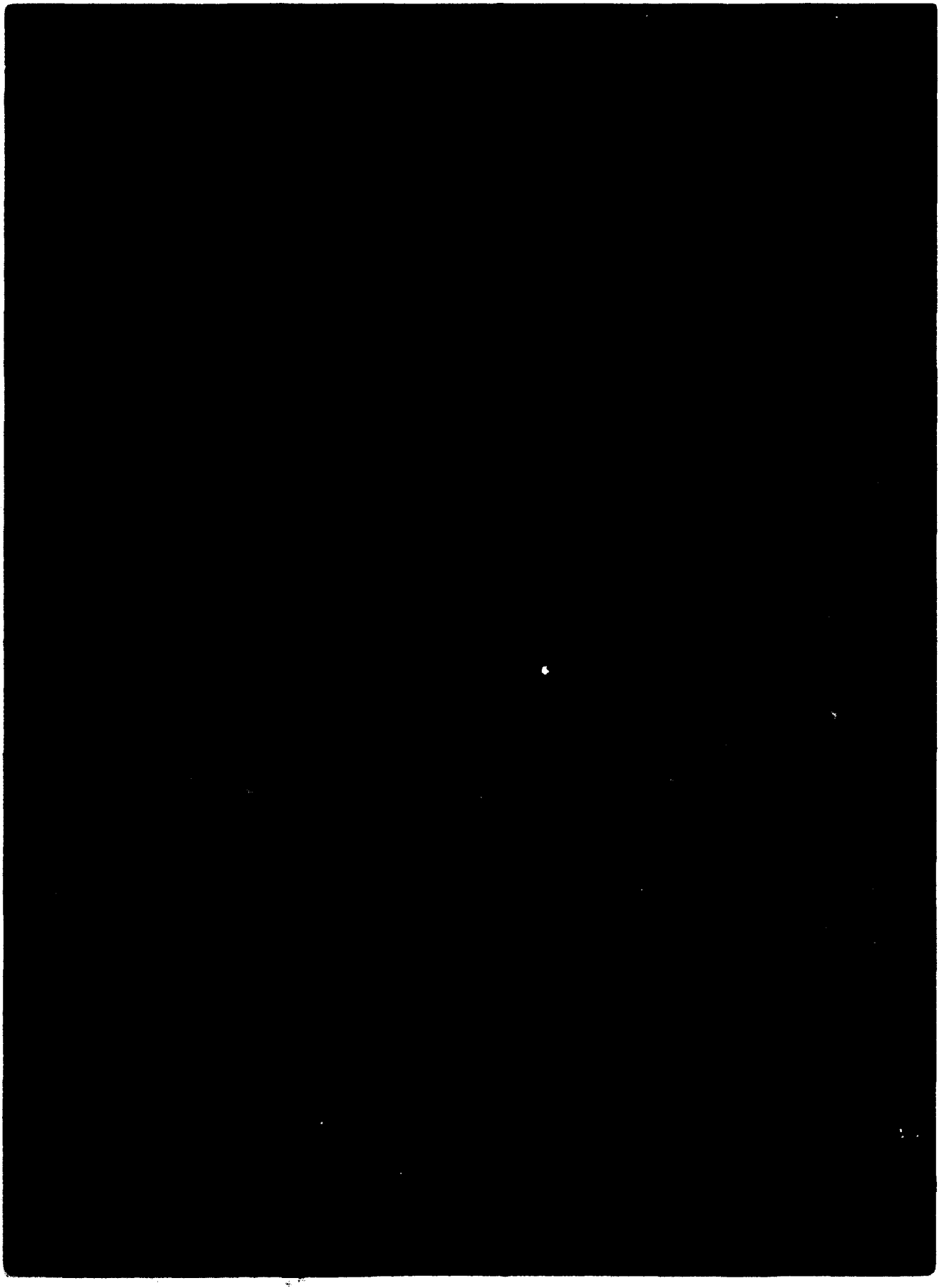

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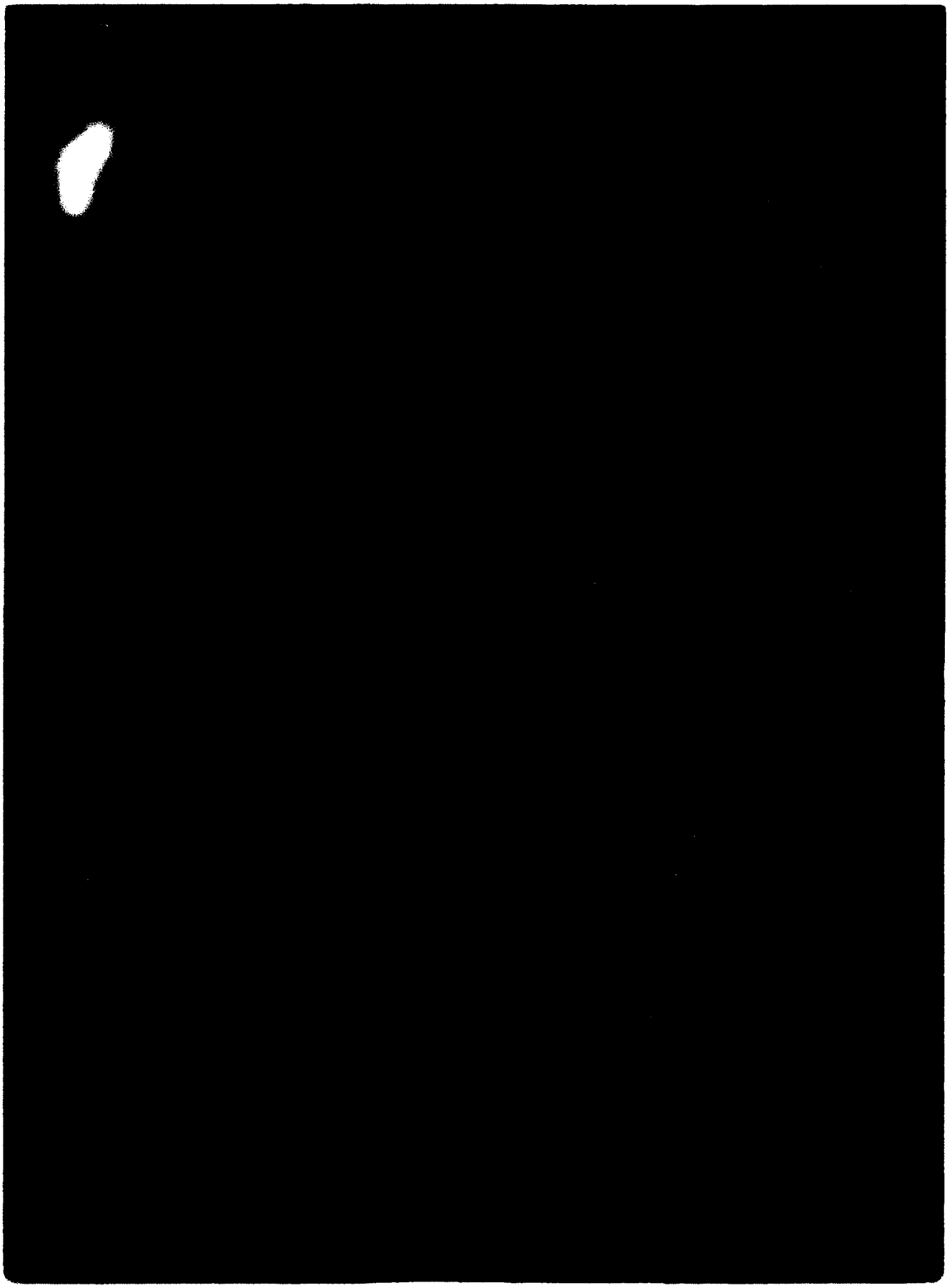

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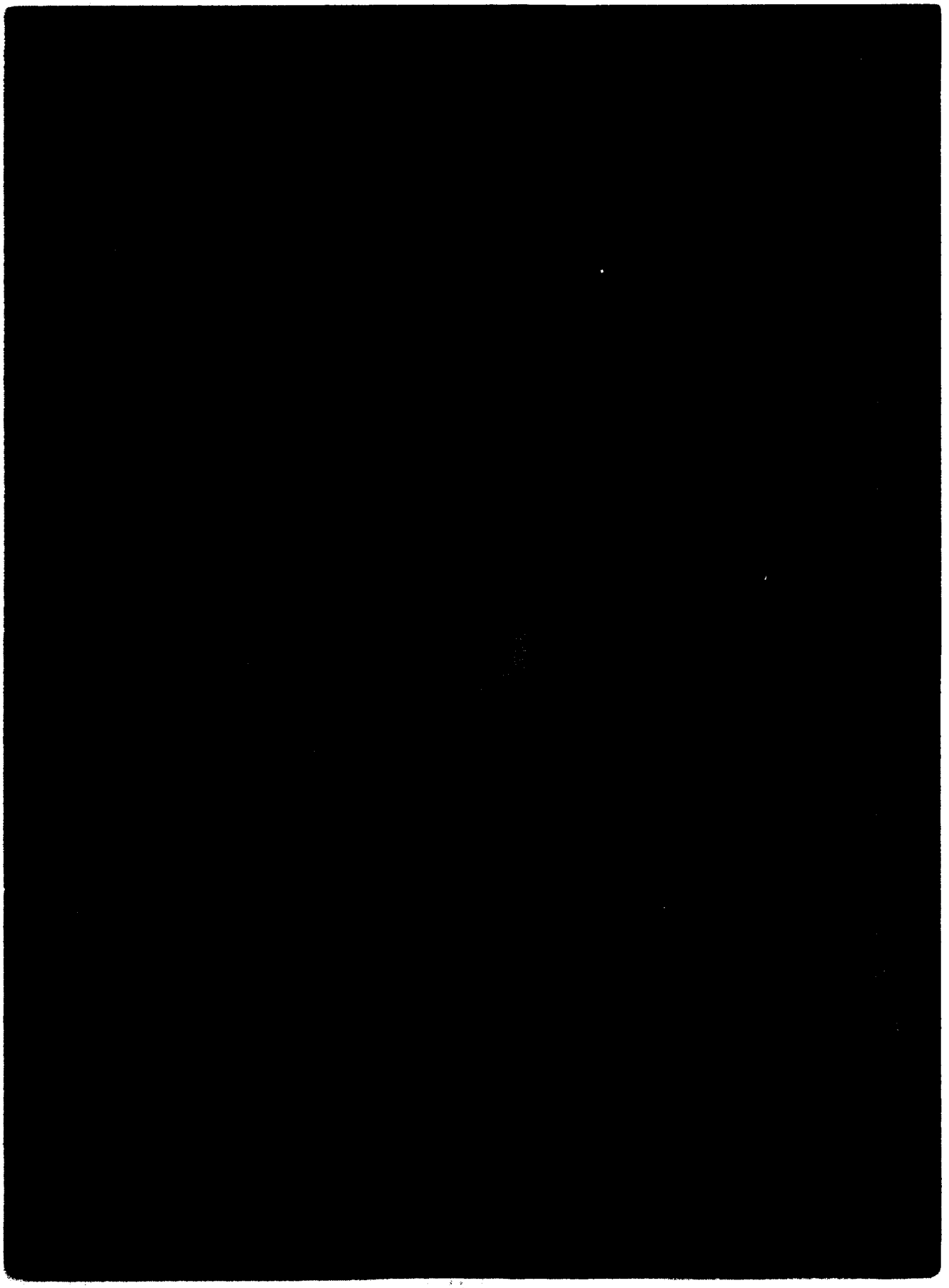

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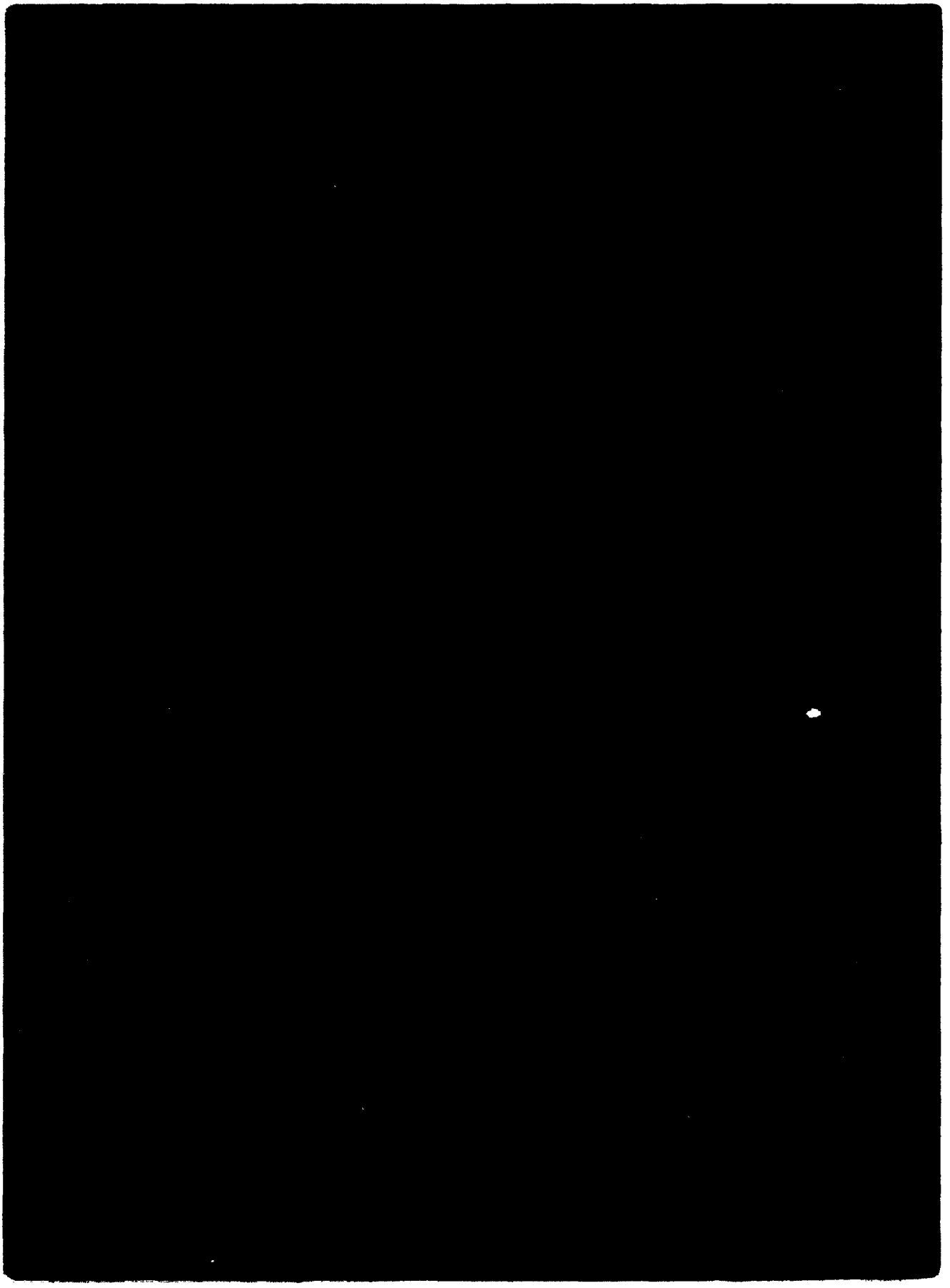

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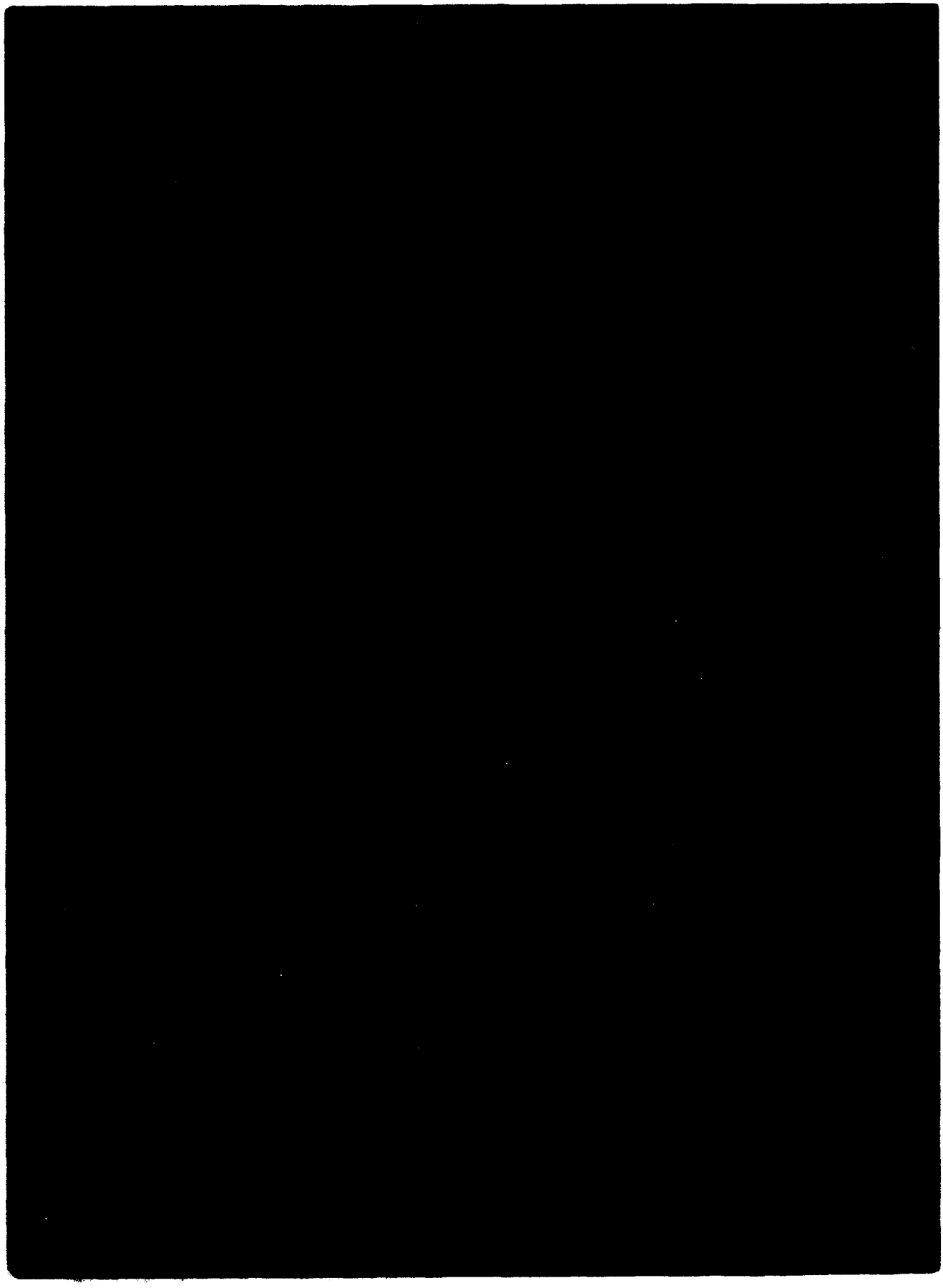

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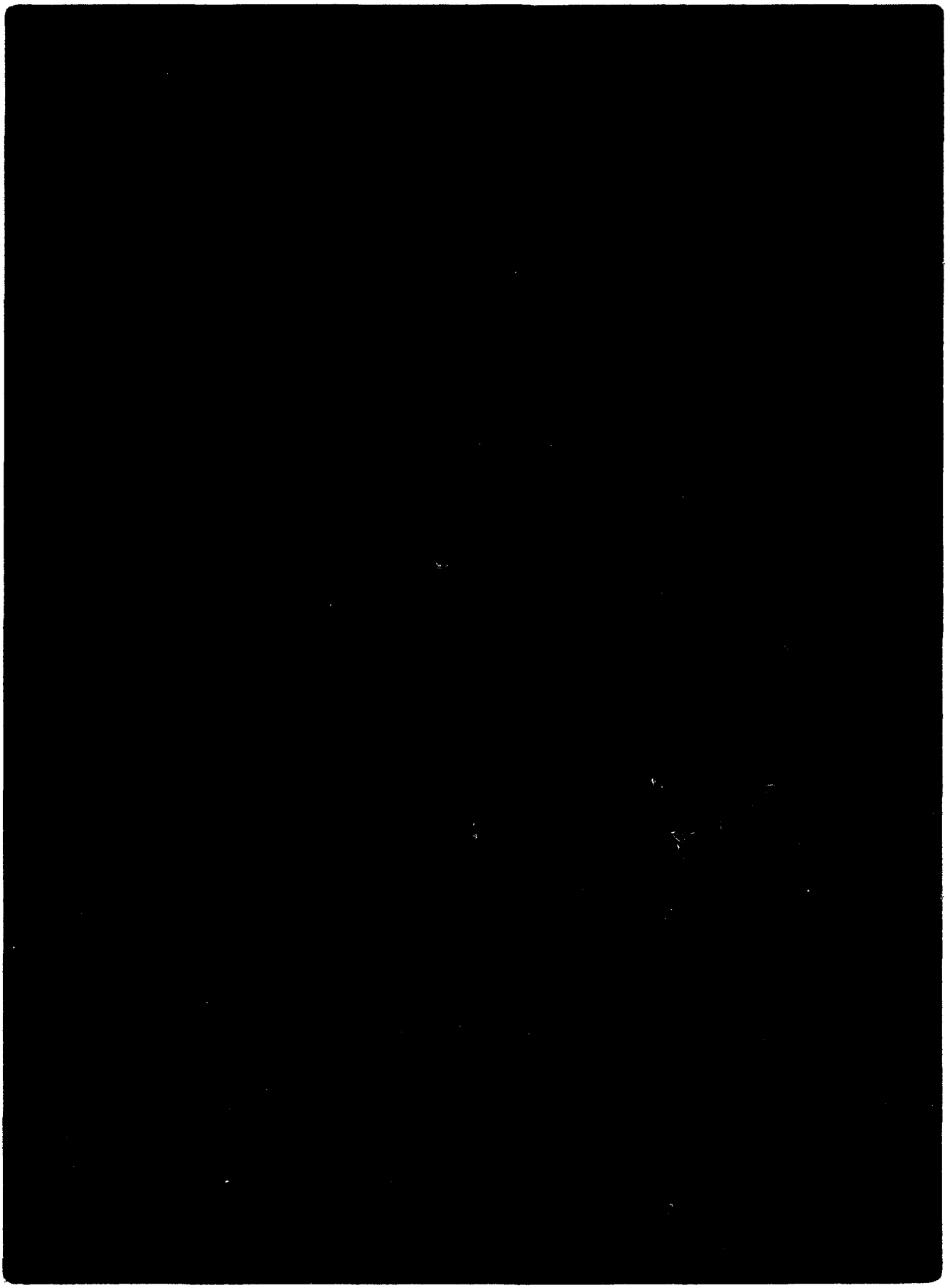

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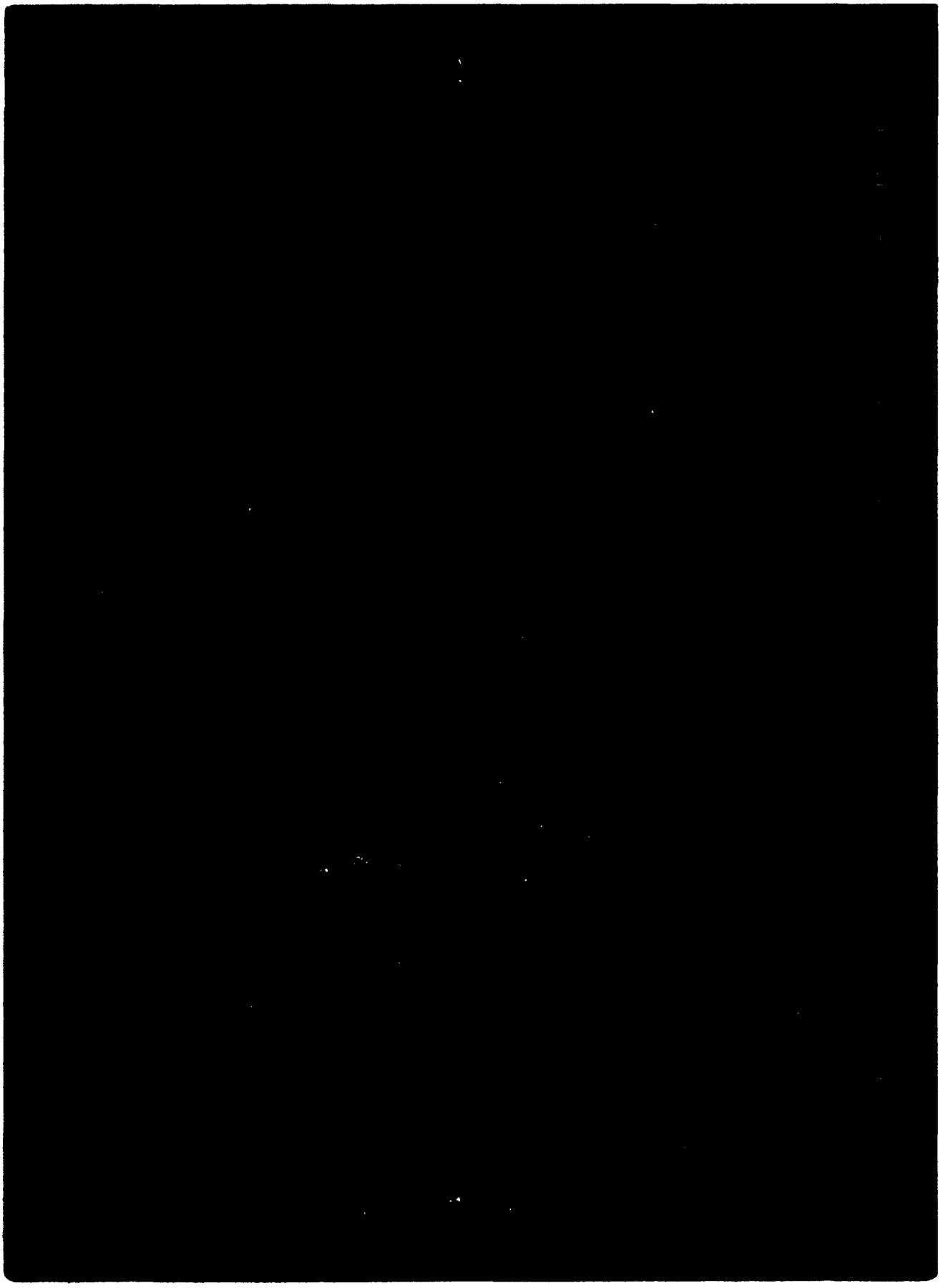

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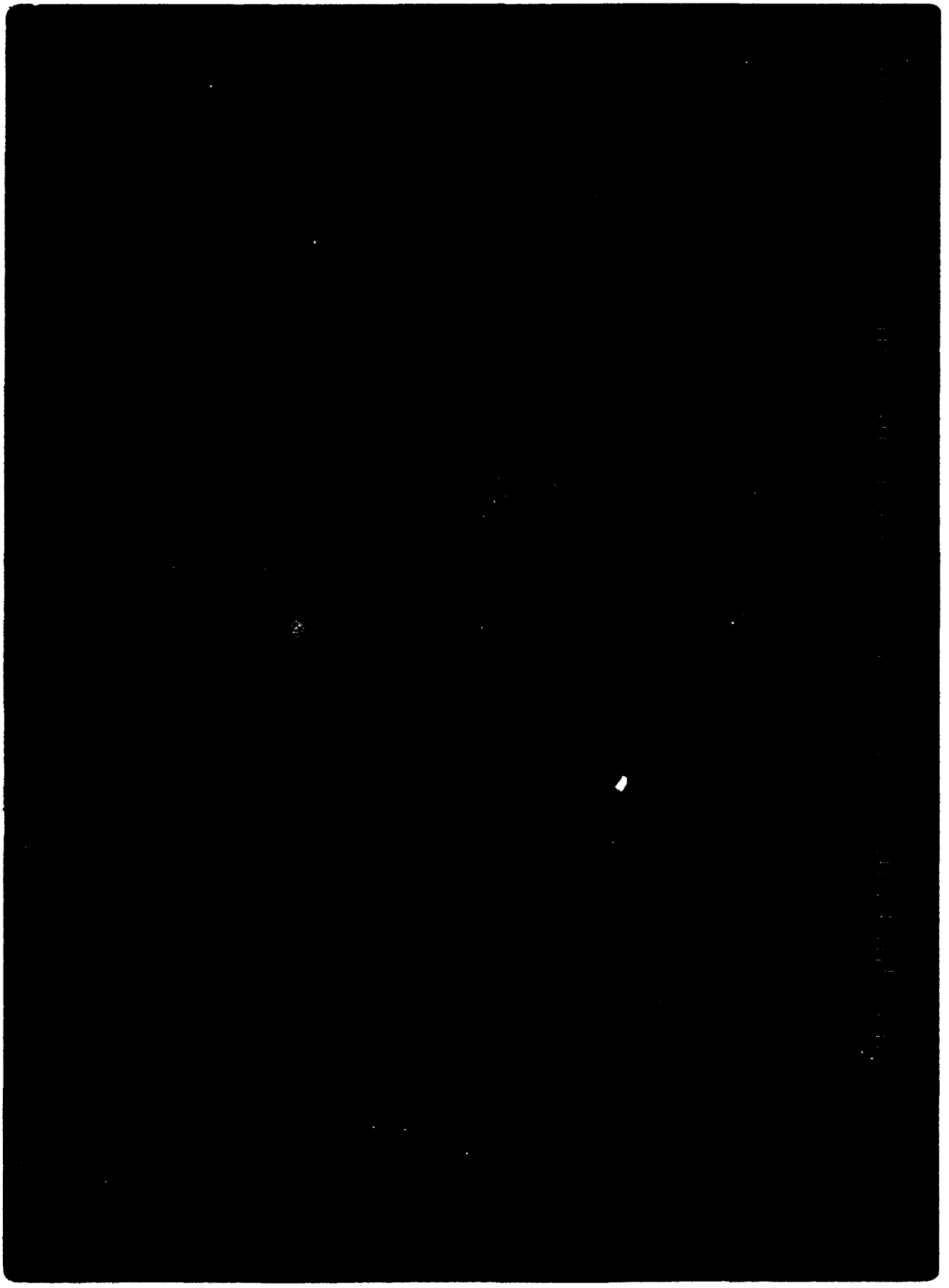

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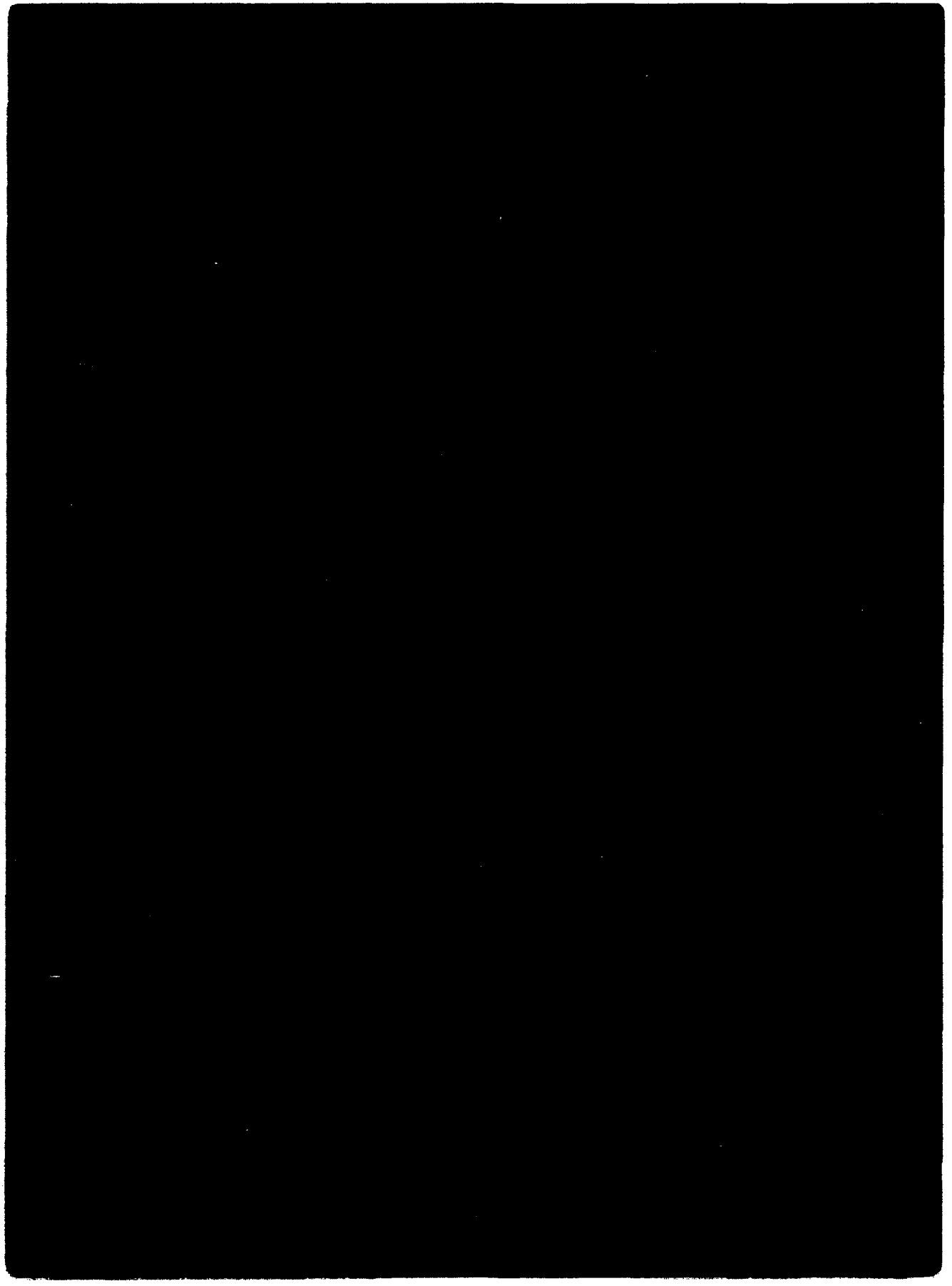

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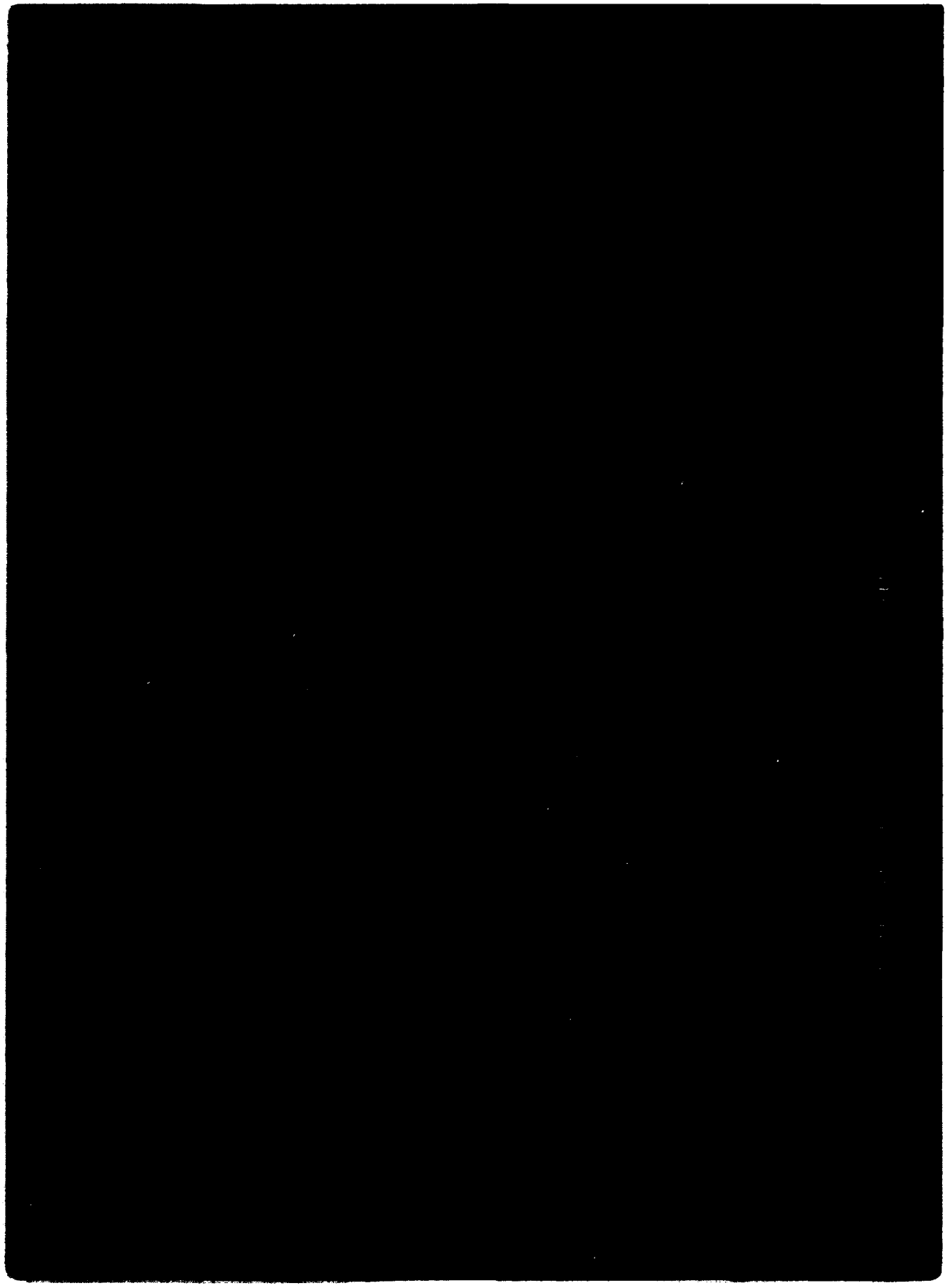

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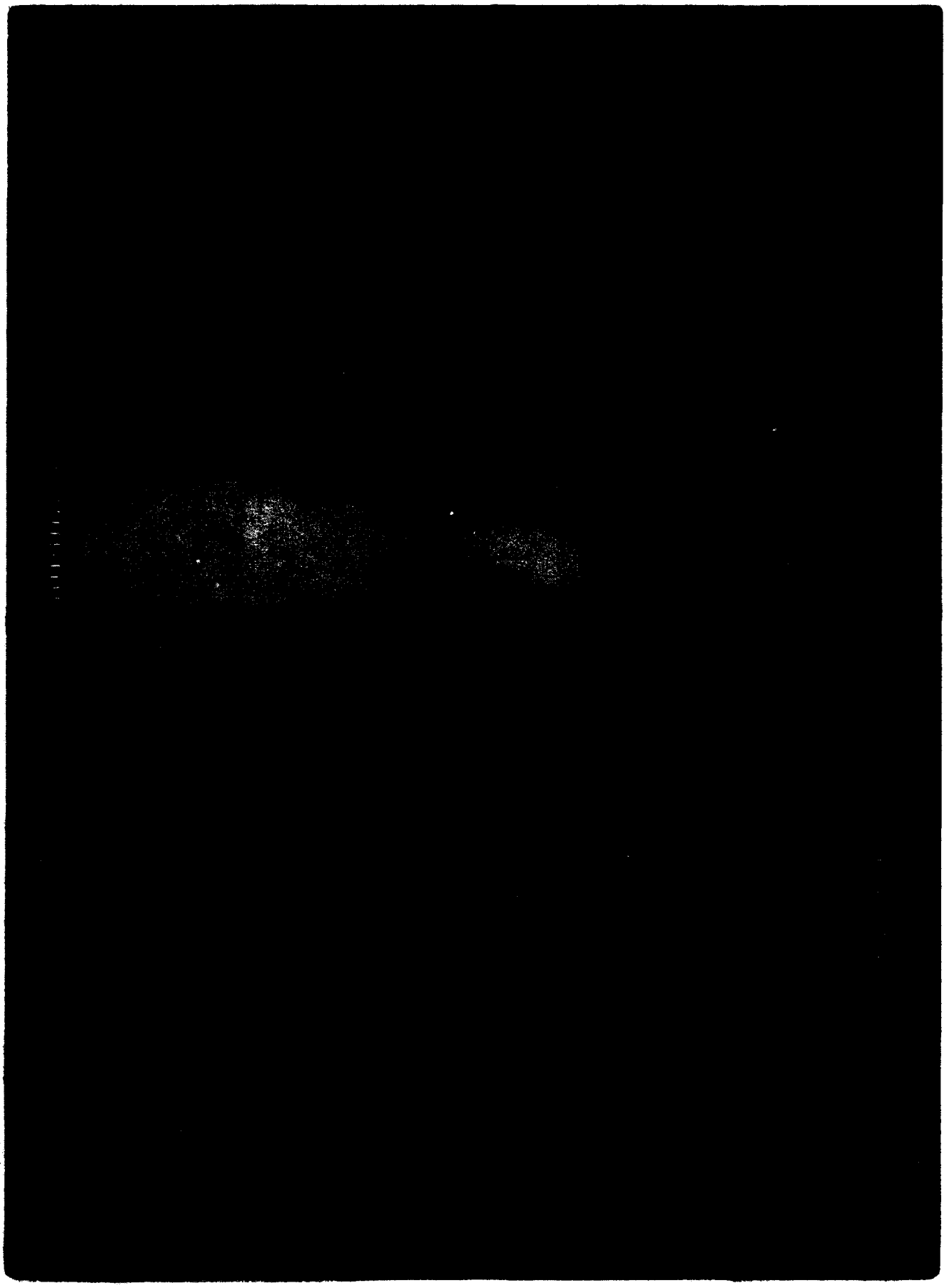

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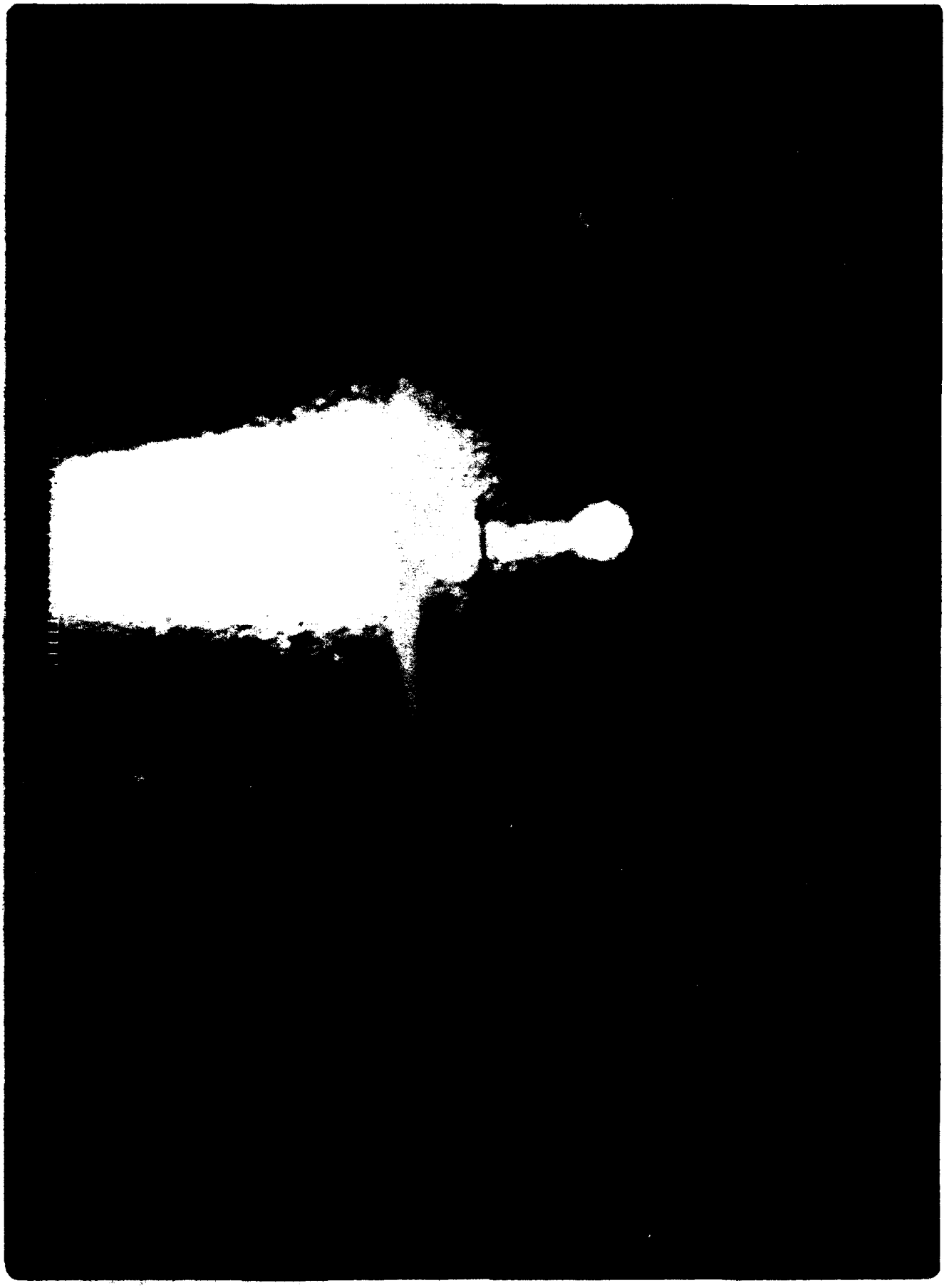

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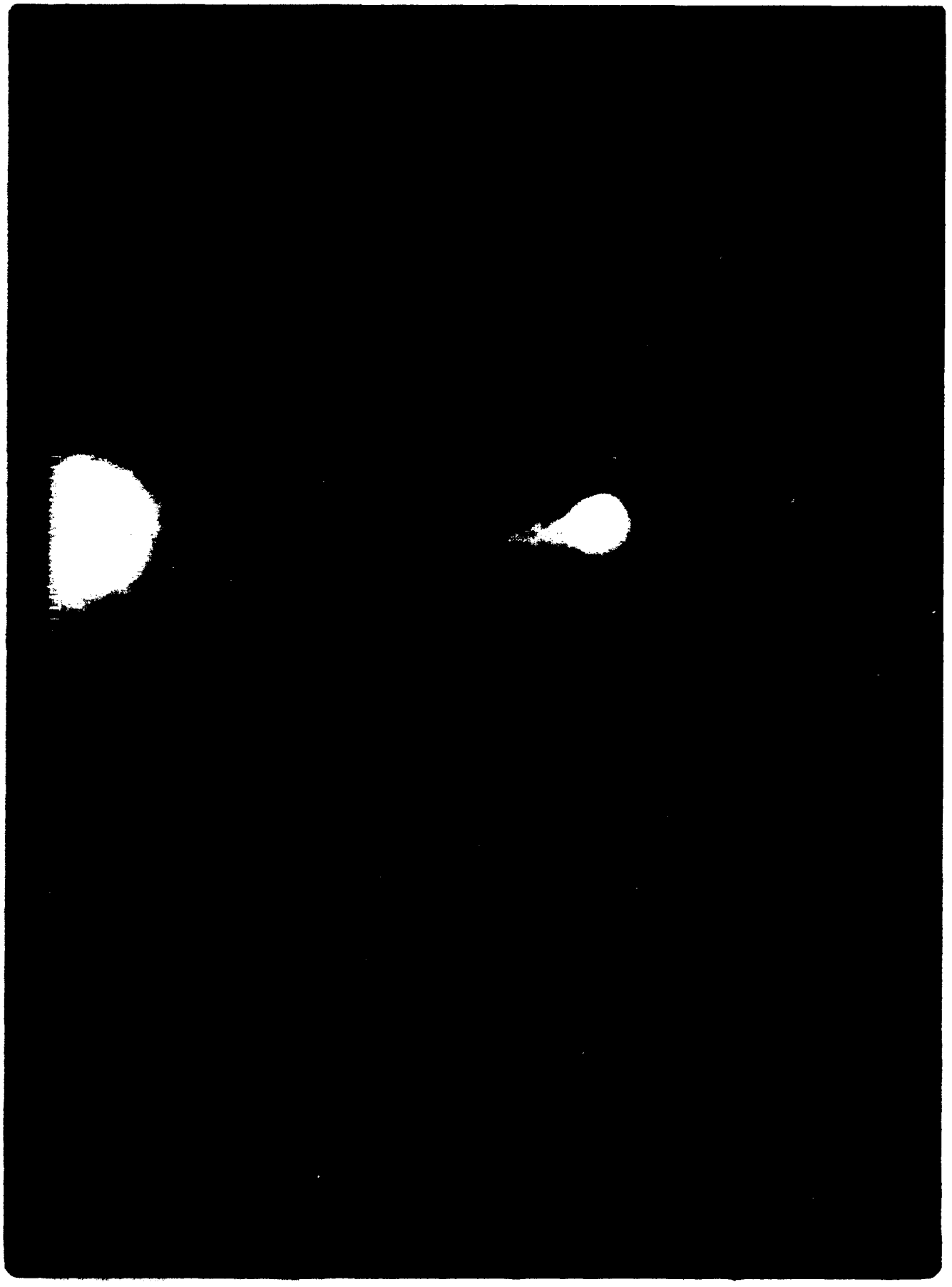


FIGURE 17

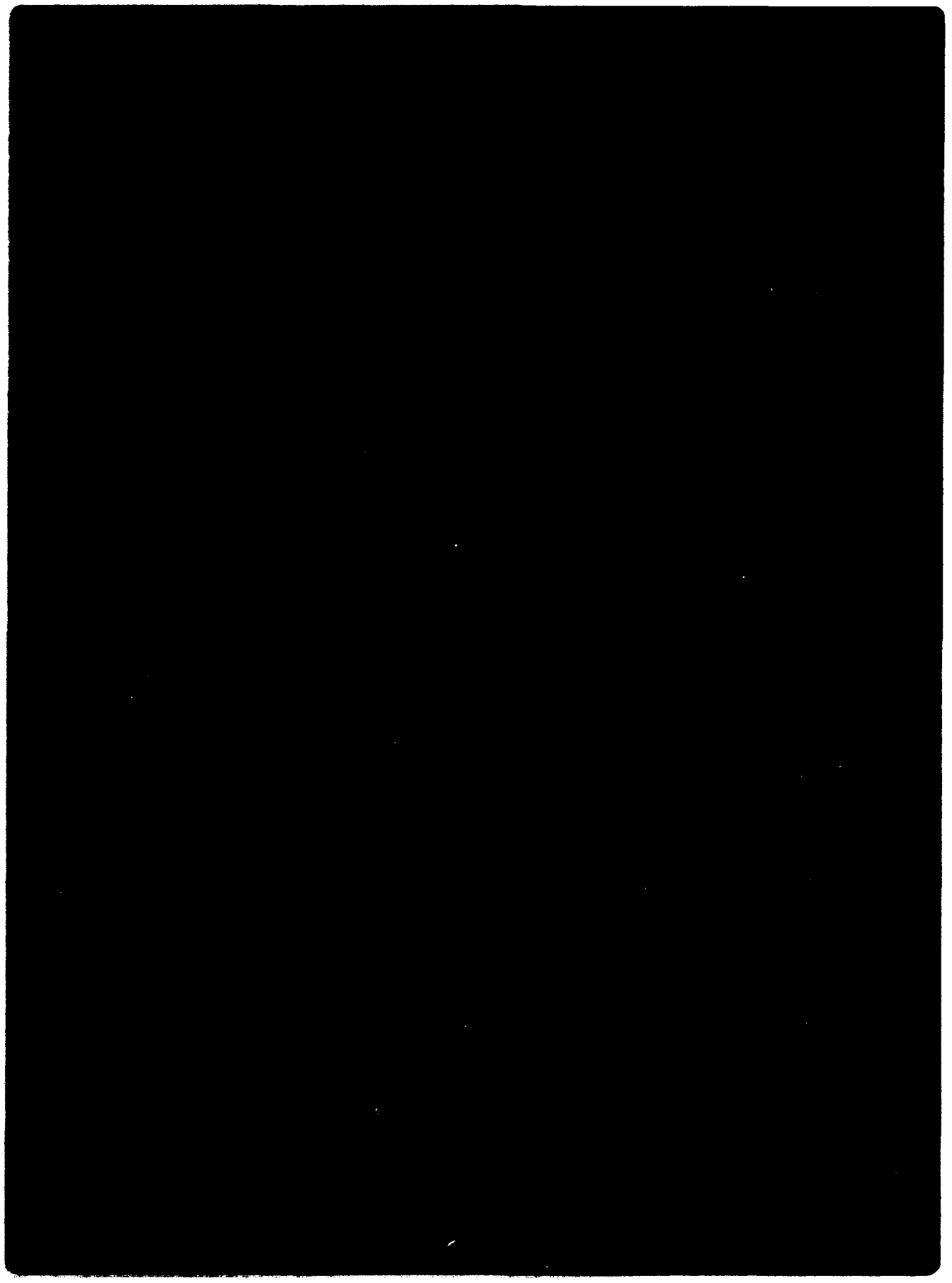
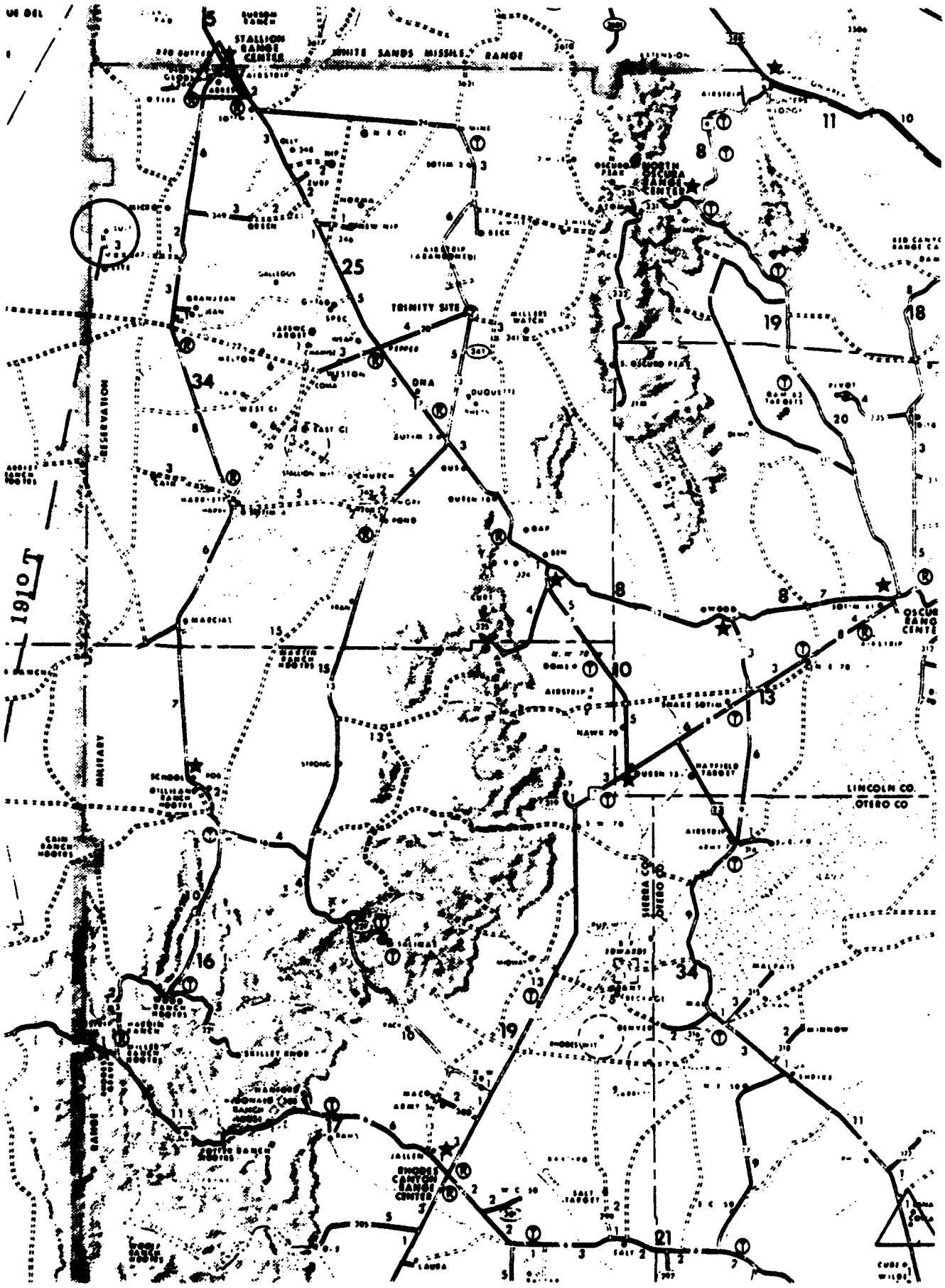


FIGURE 18

APPENDIX A

EXCEDE III WHITE SANDS MISSILE RANGE

GROUND OPTICS SITE LOCATIONS


STALLION RANGE CENTER
WHITE SANDS MISSILE RANGE
TRINITY SITE
ORNA
NORTH OSCURA RANGE CENTER
OSCURA RANGE CENTE
RHODES CANYON RANGE CENTER
LINCOLN CO.
OTERO CO
SIERRA CO.
OTERO
RESERVATION
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APPENDIX B

EXCEDE III Celestial Star Field Backgrounds from WSMR RIM FIRE Site and COWAN Site

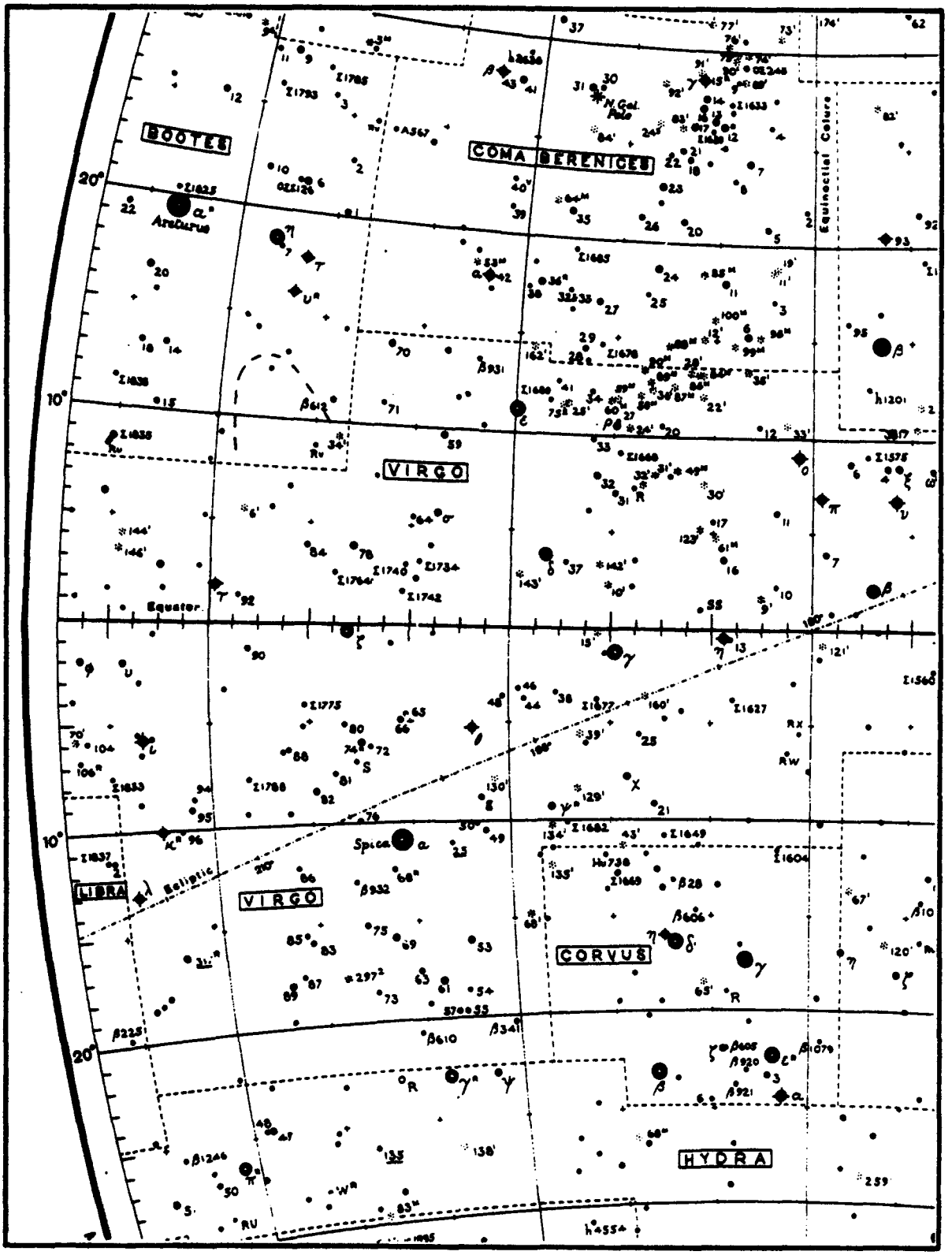

Figure B-1. EXCEDE III Celestial Sky Background from WSMR RIM FIRE Site Perspective. Upper Trajectory Shown.

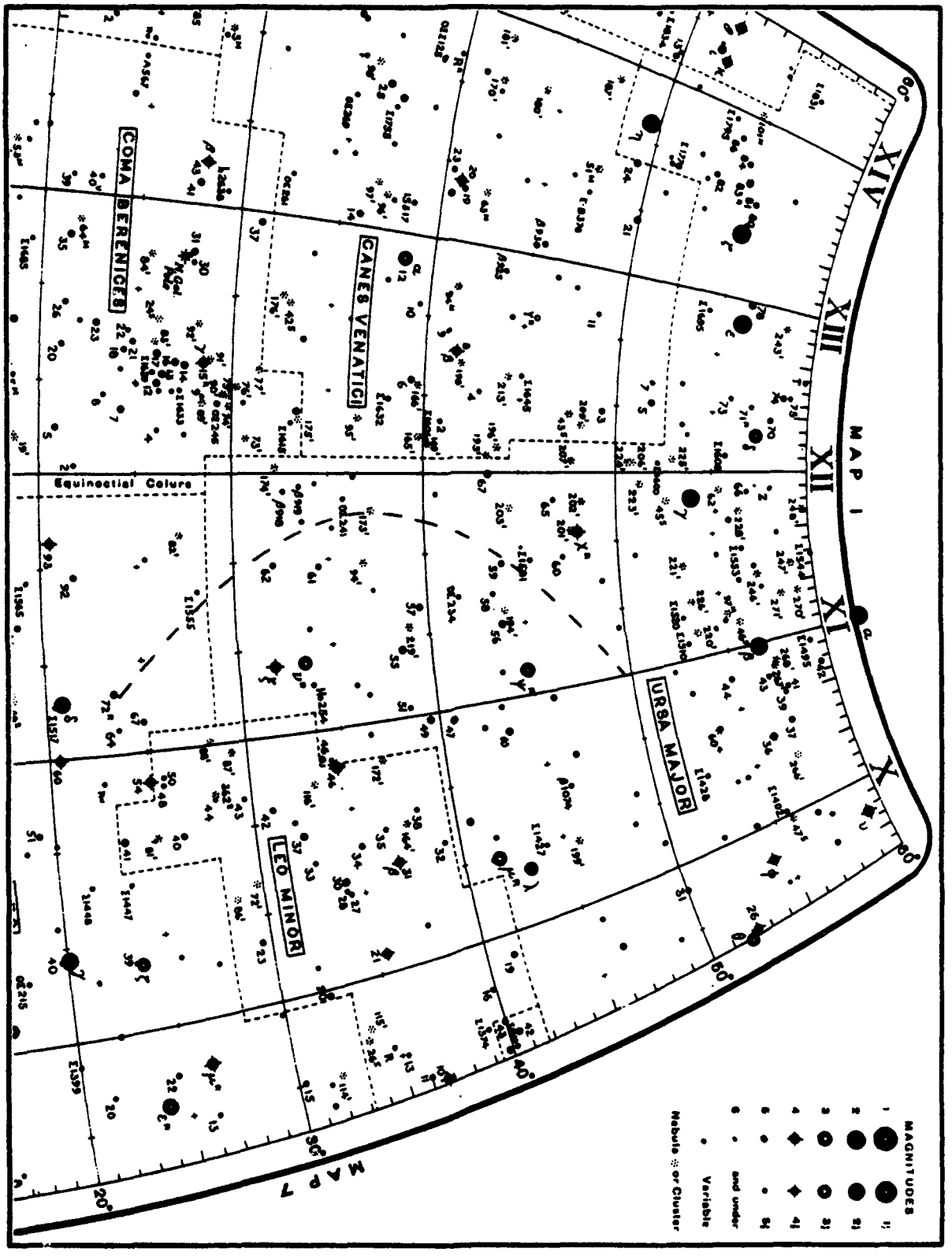

Figure B-2. EXCEDE III Celestial Sky Background from WSMR COWAN Site Perspective. Upper Trajectory Shown.

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